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Area Properties of Television Pictures

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Abstract

Area size distributions are measured for four different still pictures formed of 510 x 512 elements linearly quantized to (8) eight amplitude levels (3 bits). The initial results of this continuing measurement program indicate that for the measured pictures:

(1) First order brightness distributions tend to be uniform.

(2) The largest number of areas occur for the intermediate grey levels, with considerably fewer areas encountered at either black or white.

(3) The average size of black or white areas is larger than for the intermediate greys.

(4) Black and white areas appear to be more simply connected than intermediate grey areas.

(5) The frequency of occurrence of areas of size n-elements falls off with n a little slower than $1/n^2$.

(6) The area size distributions for each picture appear quite similar; the greatest difference between them are in the area size range 20-200 elements, and in the presence or absence of one or two very large areas.

From the data reported it is concluded that at least half of the discrete brightness areas in the picture have doubtful visual significance.

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Area Properties of Television Pictures

I. INTRODUCTION

It has long been recognized that ordinary raster scan television results in a highly redundant transmitted signal. There are many reports in the literature of measurements of various statistics of the video signal to identify this redundancy and estimate its magnitude. Most of these measurement efforts have been prompted by attempts to reduce the bandwidth and/or power transmission requirements of television signals through the recognition and removal of specific statistical redundancy.

First-order amplitude statistics of the television signal were measured by Kretzmer.[1] His findings indicate (from a small sample of pictures) that the amplitude probability distribution of a television signal is nearly uniform. There is a tendency for black elements to predominate over white ones, but this trend is very slight. Seyler[2] assumes that the measurement of a large number of typical television pictures would yield a uniform composite first-order amplitude distribution.

Schreiber[3] measured higher-order statistical dependency in the video signal. Specifically, the measurement of second- and third-order amplitude statistics along a single scan line was reported. The results indicate considerable correlation between adjacent elements along the scan line. From Kretzmer's[1] measurements of the distribution of the difference signal between adjacent elements, it is con-

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cluded[2] that the probability that two adjacent elements have the same grey level is about 10^6 times the probability that they differ by the maximum possible amplitude difference.

Run length measurements along a horizontal scan line have also been considered by Seyler[2], Capon[4] and others. In general, television picture run lengths of the order of 4 to 30 elements are prevalent. Recent measurements reported by Cherry et al[5] indicate that horizontal run lengths obey (approximately) a Poisson distribution.

Measurements of the television signal auto-correlation function along a single scan line, between scan lines, and from frame-to-frame have been made by Deriugen.[6] These results indicate, as expected, that the television signal remains highly correlated for about 50 elements, 40 lines and 30 frames (with respect to American Standard television parameters). Seyler[7] has also measured the extent to which the video signal differs in successive television frames.

Most of the preceding statistical measurements have been applied to estimate the bandwidth reduction potential of specific statistical coding schemes. The research program which prompts the measurements reported here is aimed at developing narrow-band television signal transmission techniques based largely on properties of the human visual system, the ultimate receiver of video data. In estimating the potential of such techniques, the need arises for the measurement of several new statistical parameters of the television signal.[8] Foremost among these is the area size distributions of pictures. Our interest in area statistics follows from the fact that the eye is capable of summing independent stimulations in both time and space. While it is possible to use various individual picture elements in a given picture area to influence the perception of the remaining elements, the flexibility inherent in appealing to area-summation properties of vision depends upon the average area size and the area distribution of pictures. Of course, in this context our major interest lies in 'visual picture areas'.

A 'visual area' may be defined as a connected subset of the picture which appears to the viewer to be of constant, or nearly constant brightness when viewed in the picture context. Visual areas are usually delineated by sharp boundaries; that is, perceived step changes in brightness level. In fact, a visual area probably must be substantially surrounded by other visual areas or regions of constant texture. It is not our purpose here to explicate this definition, but rather to contrast it with the convenient mathematical definition of an area used in the succeeding measurements.

For measurement purposes, a picture is a rectangular grid of points. Each point is a three bit number representing a linearly-quantized brightness level. An area is a subset of the picture points, each member of which is adjacent to at least one other member of the set; and, finally, two points are adjacent if their x and y coordinates differ by at most one element position. The deficiencies of this area

definition with respect to the concept of a 'visual area' are apparent: (1) the resulting area distribution will likely be influenced by noise, particularly in the occurrence of small areas, (2) many areas will not be visual areas, such as isolated points, long filaments, or complex patterns of high connectivity, and (3) some visual areas will be broken up due to 'contouring' or gradual but insignificant shifts of grey level across a visual area. On the other hand, this definition lends itself to computations and represents at least a starting point from which better, and perhaps more subtle, departures can be made.

2. AREA MEASUREMENTS

The actual statistical measurements were made with a PDP-1 computer using a systematic search procedure and computation program described in Nishikawa.[9] The picture brightness data were stored in digital form on magnetic tape. The data was taken from black-and-white transparencies with a flying-spot scanner and analog-to-digital conversion equipment described in Pan, Gronemann, et al.[10] Each brightness element of the 510 x 512 picture matrix was linearly quantized to 10-bits precision. However, system noise considerations preclude reliance on the last 4 or 5 bits. In the measurements reported here, only 3-bit quantization (produced by the PDP-1 using a suitable round off routine) was used.

A group of four pictures (shown in Figure 1) was selected for the initial measurements. In addition, the area size distribution of a matrix of nearly equiprobable independent brightness levels (noise) was measured for comparison. The first order brightness distributions for these pictures are shown in Figure 2. Most of the measured points are within an octave of the relative frequency appropriate for a uniform distribution. The composite first order distribution for the four pictures (also shown in Figure 2) is more uniform, but has a downward slope going from black to white elements. Most of this trend can be attributed to the skewed brightness distribution of 'photographer'. This outdoor scene has relatively little highlight region.

The number of discrete picture areas at each brightness level is shown in Figure 3. Note that the composite distribution deviates substantially from the uniform first order composite brightness distribution. The first conclusion which can be drawn from a consideration of the composite curves in Figures 2 and 3 is that, while there are far more 'grey' areas than black or white ones, the black and white areas are considerably larger to produce the nearly uniform composite first order brightness distribution. A detailed examination of the individual picture distributions indicates that the average sizes in levels 0 and 1 (black and near black) and level 7 (white) are considerably larger than those in levels 2, 3, 4, 5, or 6. This data is compiled in Table 1 along with median and average area sizes for each

(a)
'Crowd'

(b)
'Photographer'

(c)
'Portrait'

(d)
'Cloud'

NOTE: These photographs were taken from a flying spot scanner whose output has been quantized to 3 bits. The contouring which accompanies such gross quantization is clearly evident.

Figure 1. Measured Pictures

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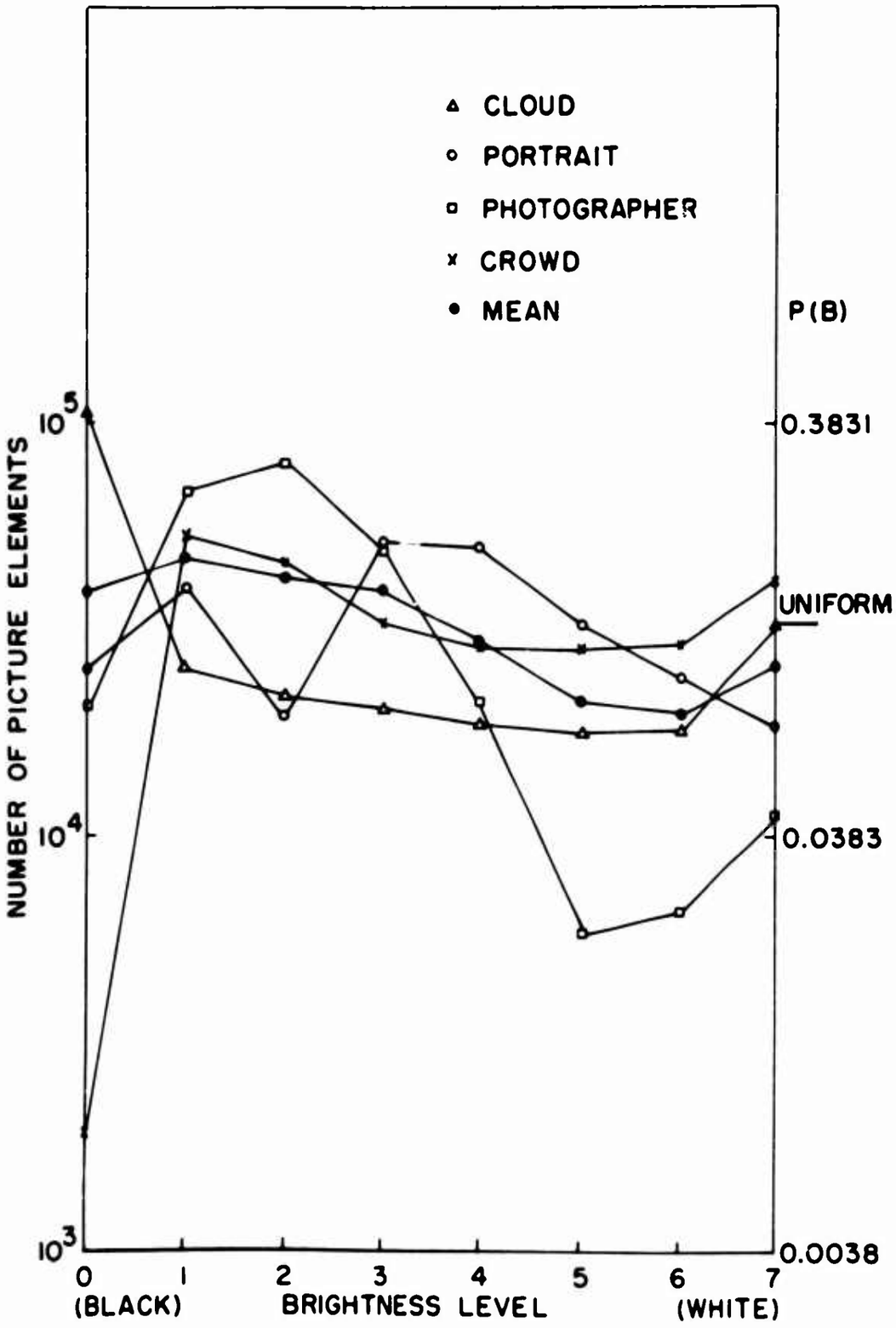


Figure 2. First Order Brightness Distributions

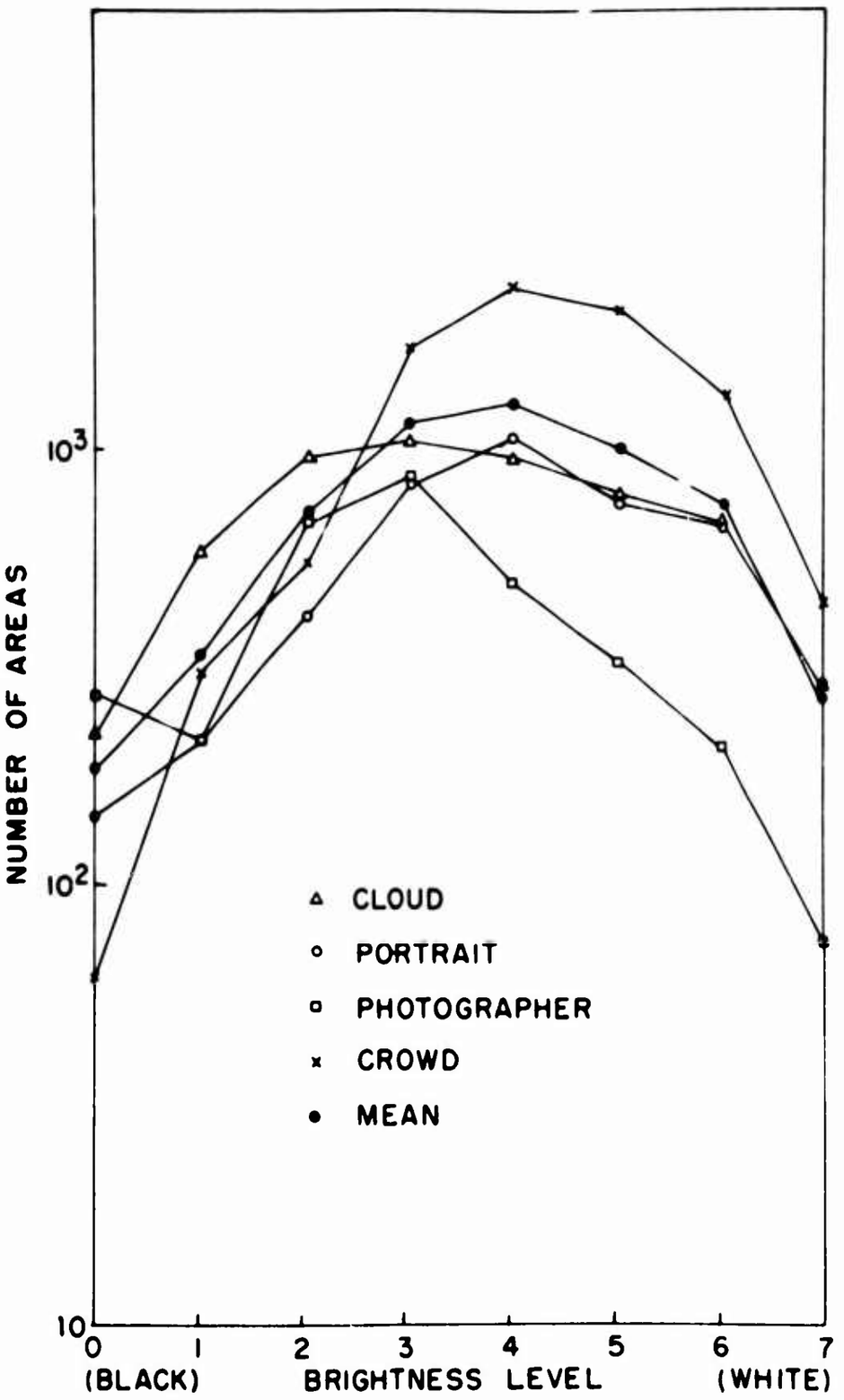


Figure 3. Number of Picture Areas versus Brightness Level

TABLE 1. Tabulation of area size measurement data

Brightness Level	Portrait		Crowd		Cloud		Photographer		Average Value of $\bar{n}$
	N_A	$\bar{n}$	N_A	$\bar{n}$	N_A	$\bar{n}$	N_A	$\bar{n}$	
0 (Black)	144	177	62	29	225	467	280	71	214
1	220	189	310	171	580	44	220	314	141
2	680	29	550	83	950	22	680	116	58
3	870	59	1720	19	1020	20	870	56	34
4	1060	47	2350	12	970	20	500	42	24
5	760	42	2080	14	790	22	330	17	21
6	680	35	1360	21	690	26	210	31	24
7 (White)	280	65	440	94	280	114	75	147	99
Total Number of Areas in Picture	4421		8872		5543		3153		
Average Area Size (elements)	59		29		47		83		
Median Area Size (elements)	1.50		2.43		3.75		1.35		

N_A = number of areas $\bar{n}$ = average area size (elements)

*Median sizes are expressed in non-integer quantities to provide greater insight into the area distribution in the region of the median value.

**All figures connected with N_A and $\bar{n}$ have been rounded off in this table and thus totals may not agree.

of the four pictures. Median area sizes less than 4 elements reflect the great preponderance of small areas in the picture. On the other hand, average area sizes depend mainly on the very few large areas which generally form the background of the picture. The absence of such a background, as in 'crowd', results in a very small average area size.

Typical experimental data from an area measurement are presented in Figure 4. The histogram represents the relative frequency of occurrence of areas of size-n versus n for the picture called 'photographer' (see Figure 1b). The width of each interval along the horizontal axis reflects the range of area sizes which must be considered before a minimum of 10 areas are encountered. The intervals from $1 \leq n \leq 20$ generally contain a single area size. The vertical coordinate of the histogram is derived by dividing the number of areas counted in an interval by the width of the interval. The vertical coordinate has been normalized through further division by the total number of areas in the picture.

The smooth curve drawn through the histogram values in Figure 4 illustrates how the curves in Figures 5 and 7 were obtained. In general, these smooth curves fall close together for all four pictures (see Figure 5) and indicate that the relative frequency of occurrence of areas of size-n falls off a little slower than $1/n^2$. The greatest deviation between the curves occurs in the size range 20 to 200 elements. Furthermore, the greatest deviation from the smooth curve approximations of frequency of occurrence data occur in the same size range. These areas, most of which are large enough and of appropriate connectivity to be visually significant, may be the key areas for form perception in the picture.

The photographs in Figure 6 illustrate several additional features of the area size distribution as a function of grey level. The white regions of each photo represent the segment of the picture 'crowd' (Figure 1a) formed of elements of the given brightness level. In general, the areas formed of black and white elements are more simply connected, as well as larger. The middle grey levels tend to be arranged in long filaments or outlines. These grey levels appear to provide shading rather than boundary definitions.

To provide a comparison between the images in Figure 1a, b, c, and d and a random pattern of independent brightness elements having a similar first order brightness distribution, the area size distribution of a noise image was measured. A smooth curve approximation of this measured data is also shown in Figure 4. The area distribution resulting from the noise source is quite different from any of the measured pictures. The median area size of the noise pattern is 0.97 elements and the average area size is 2.3 elements.

The segment of total screen area covered by elementary areas of various sizes is shown in Figure 7. The curves in Figure 7 are developed by multiplying the vertical coordinate of each section of the relative frequency histogram by the average value of n over the segment of the histogram. The percentage of screen area covered by areas of size-n tends to fall off a little slower than $1/n$.

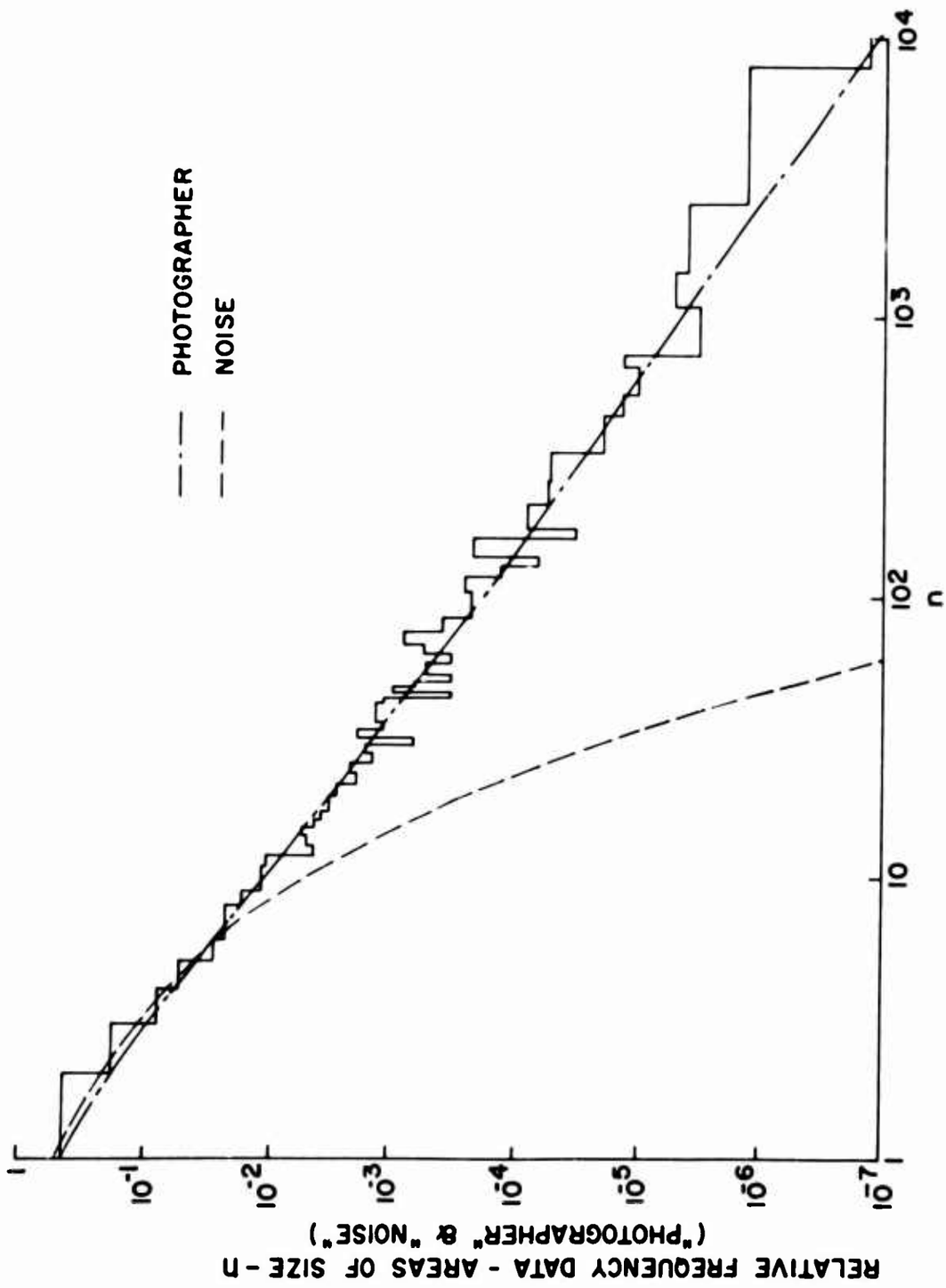


Figure 4. Frequency of Occurrence - Areas of Size-n versus n

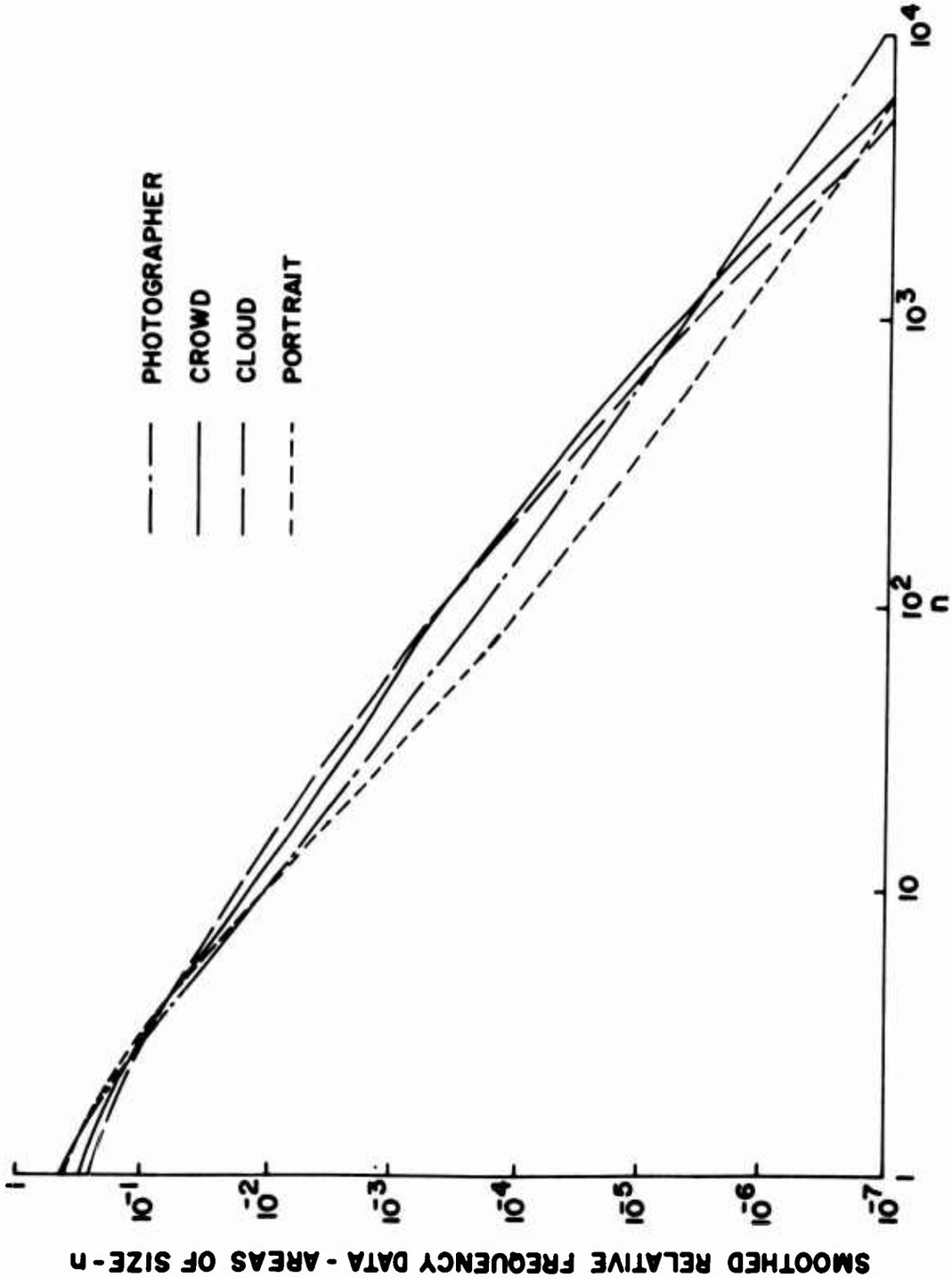
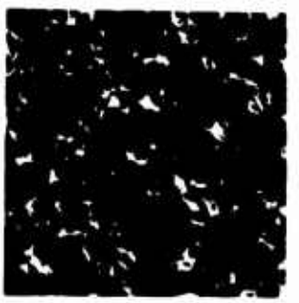


Figure 5. Smoothed Relative Frequency Data - Areas of Size-n versus n

Level 0 (Black)

Level 1

Level 2

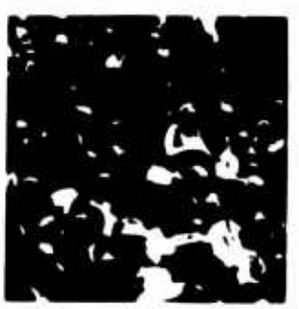


Level 3

Level 4

Level 5

Level 6



Level 7 (White)

Figure 6. Area Shapes as a Function of Grey Level

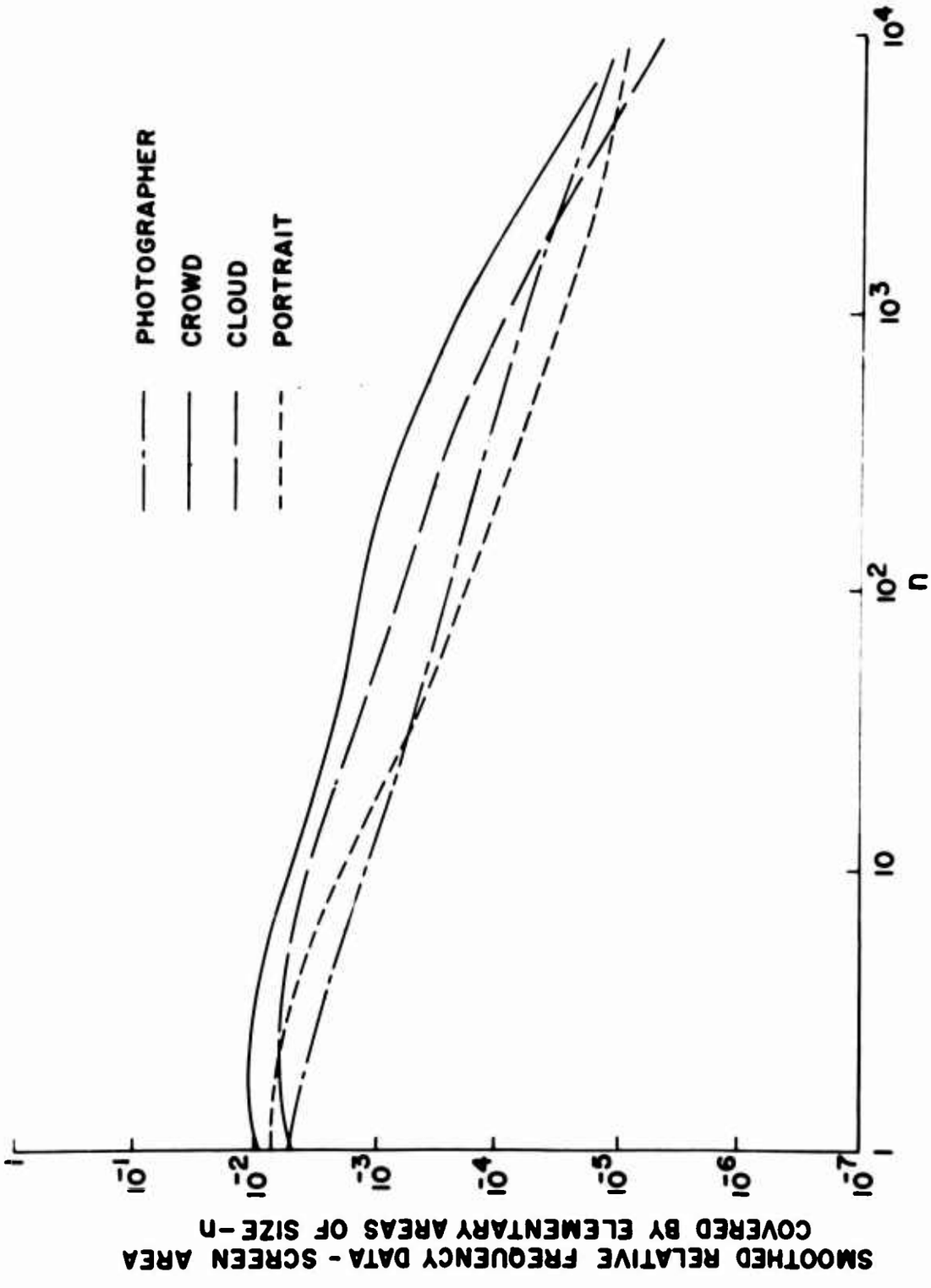


Figure 7. Relative Screen Area Covered by Elementary Areas of Size-n versus n

3. DISCUSSION

The measurements reported here are the first in a continuing program aimed at providing an understanding of the area properties of TV images. Relatively few features of the area measurements reported can be estimated by visually examining the pictures. Though these measurements do not establish the visual or perceptual significance of areas of different sizes, they do raise several questions in this regard.

In the limited sample of pictures (four) measured, areas of 1, 2, and 3 elements account for over 50% of the discrete areas in the picture and cover about 5 to 10% of the total picture area. It is unlikely that faithful grey-level reproduction of such areas is required for good quality time-varying (or moving) pictures. For instance, the 'synthetic highs' technique proposed by Schreiber, Knapp, and Kay[11] is based to a considerable extent on the fact that the eye will tolerate considerable grey-level error in regions of high picture detail. Identification of such small area (or high detail) regions of the picture through the measurement of area-size distribution is very nearly the two-dimensional analog of identification of these regions through high pass filtering of the raster scan video signal.

The measured area size distributions for the individual pictures appear quite similar and vary smoothly for all pictures for area sizes less than 20 elements. Above 20 elements, each picture has far more variation in its frequency histogram and the approximate best-fit curves differ between pictures. While there is really very little data on area sizes above 1000 elements, there is a trend toward greater agreement between pictures at large area sizes. The area range, 20 to approximately 200 elements, may represent the critical size areas in TV picture perception.

Further measurements should explore the effects of amplitude quantization, noise, and source material on area size distributions, and also determine the visual effects which result from modifications of area properties through transmission.

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